TOWARDS A PATIENT-SPECIFIC *IN SILICO* MODEL TO ACCURATELY QUANTIFY IMPLANT PRIMARY STABILITY IN OSTEOPOROTIC BONE

+[1]Juri A. Steiner, [1]Patrik Christen, [1]Stephen J. Ferguson, [1,2]G. Harry van Lenthe

[1]*Institute for Biomechanics, ETH Zurich, Zurich, Switzerland;*
[2]*Biomechanics Section, KU Leuven, Leuven Belgium*
steineju@ethz.ch

Introduction

Recently, we demonstrated that micro-finite element (µFE) models can accurately predict the apparent stiffness of single screws fixed in human trabecular bone when a thin peri-implant bone damage region was included in the model [1]. Although we now have a refined µFE model at hand that provides accurate predictions of primary implant stability, this model has only been validated using single screws in human trabecular bone. Hence, in this study, our aim was to establish a proof of concept for a patient-specific computational method to assess primary stability for a multi-screw implant system in human osteoporotic bone and to develop the methodology to validate these models.

Methods

A human cadaveric humerus was scanned twice using micro-computed tomography (µCT), once before ('intact model') and once after osteotomy and implant instrumentation ('instrumented model'). Through image processing, two µFE models were created: one representing the intact bone and one representing the instrumented bone. Between the two µCT scans and after the implant insertion, *in vitro* mechanical tests were conducted from which the apparent stiffness of the intact and instrumented bone was measured, respectively. All µFE simulations were performed with ParOSol [2]. For the intact model, the patient-specific bone tissue modulus was determined, such that the model predicted the apparent stiffness as measured experimentally. The same bone tissue modulus was used for the instrumented model. Additionally, in the instrumented model, a thin peri-implant damage region was added, represented by a Young's modulus lower than that of intact bone. The displacements of 12 motion capture markers placed on various positions of the specimen were measured with a dual camera system and served as the ground truth for validating the computational analysis. In the µFE model, the displacement within the regions of the same 12 motion capture markers was computed.

Results

For the intact computational model, a bone tissue modulus E_{Bone} = 7.35 GPa provided a perfect match in apparent stiffness between the *in silico* and *in vitro* mechanical test. For the instrumented model, and using E_{Bone}=7.35 GPa, a peri-implant bone modulus of E_{PIBD} = 0.9 GPa gave a perfect match in apparent stiffness between the *in silico* and *in vitro* mechanical test. While most of the deformation occurred close to the loading and embedding site in the intact model, most of the deformation occurred in the cortical bone around the fixation screws in the instrumented model (Fig. 1). The comparison between *in vitro* and *in silico* displacements showed a correlation of R^2=0.852 and a slope of 0.96.

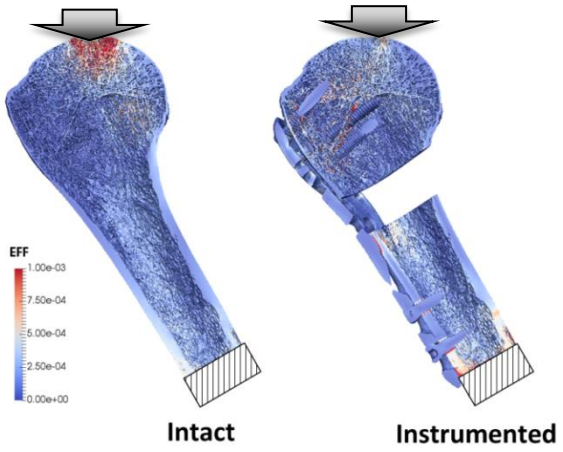

Figure 1: Effective strain is shown for both models subject to an identical external load. While in the intact model, most of the deformation occurred at the load application site, the instrumented case showed more deformation in the damaged peri-implant bone region.

Discussion

In conclusion, this study presents a proof of concept for an organ-scale µFE model of a biomechanically relevant multi-screw fracture fixation scenario as well as an experimental technique to validate these analyses.

Acknowledgements

The authors acknowledge DePuy Synthes as a material provider. Computing time was provided by the Swiss National Supercomputing Centre (CSCS).

References

1. J. Steiner (2015), How to replicate the mechanical behaviour of bone-implant systems using micro-CT based finite element analysis. *21st Congress of the European Society of Biomechanics*. Prague, Czech Republic
2. C. Flaig (2012), PhD Thesis ETH Zurich, A Highly Scalable Memory Efficient Multigrid Solver for µ-Finite Element Analyses.